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COMMERCIAL DEMONSTRATION OF THE NOXSO SO₂/NO_x REMOVAL FLUE GAS CLEANUP SYSTEM

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Project Definition Phase

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Table of Contents

1.0	INTRODUCTION	1
2.0	PROJECT DESCRIPTION	3
3.0	PROJECT STATUS	3
4.0	SUMMARY	11

1.0 INTRODUCTION

The NOXSO process is a dry, post-combustion flue gas treatment technology which uses a regenerable sorbent to simultaneously adsorb sulfur dioxide (SO_2) and nitrogen oxides (NO_x) from the flue gas of a coal-fired utility boiler. In the process, the SO_2 is reduced to elemental sulfur and the NO_x is reduced to nitrogen and oxygen. It is predicted that the process can economically remove 90% of the acid rain precursor gases from the flue gas stream in a retrofit or new facility.

Details of the NOXSO process are described with the aid of Figure 1. Flue gas from the power plant is drawn through a flue gas booster fan which forces the air through a two-stage fluid bed adsorber and centrifugal separator before passing to the power plant stack. Water is sprayed directly into one or both of the fluid beds as required to lower the temperature to 250-275°F by evaporative cooling. The fluid bed adsorber contains active NOXSO sorbent. The NOXSO sorbent is a 1.6 mm diameter γ -alumina bead impregnated with 5.2 weight % sodium. The centrifugal separator separates sorbent which may be entrained in the flue gas and returns it to the inlet of the dense phase transport system.

Spent sorbent from the adsorber flows into a dense-phase conveying system which lifts the sorbent to the top bed of the sorbent heater vessel. The sorbent flows through the multi-stage fluidized bed sorbent heater counter to the heating gas which heats the sorbent to the regeneration temperature of approximately 1150°F.

In the process of heating the sorbent, the NO_x is driven from the sorbent and carried to the power plant boiler in the NO_x recycle stream. The NO_x recycle stream is cooled from approximately 500°F to 150°F in the feedwater heater. This heater heats a slip stream of the power plants feedwater, thereby reducing the amount of extraction steam taken from the low pressure turbine, enabling the generation of additional electricity. The cooled NO_x recycle stream replaces a portion of the combustion air. The presence of NO_x in the combustion air reduces the formation of NO_x in the boiler resulting in a net destruction of NO_x .

The heated sorbent enters the regenerator where it is contacted with natural gas. Through a series of chemical reactions, the sulfur on the sorbent combines with the methane and forms SO_2 and H_2S . Additional regeneration occurs in the steam treater when the sorbent is contacted with steam converting the remaining sulfur on the sorbent to H_2S .

The regenerator and steam treater off-gas streams are combined and directed to a sulfur recovery plant where the H_2S and SO_2 are converted to a sulfur by-product. Elemental sulfur, sulfuric acid, and liquid SO_2 are all potential end products from the regenerator off-gas stream. Tail gas from the sulfur recovery plant will be incinerated and recycled back through the adsorbers to remove any sulfur compounds.

High temperature sorbent exiting the steam treater passes to the multi-stage fluidized bed sorbent cooler. The sorbent flows counter to the ambient air which cools the sorbent.

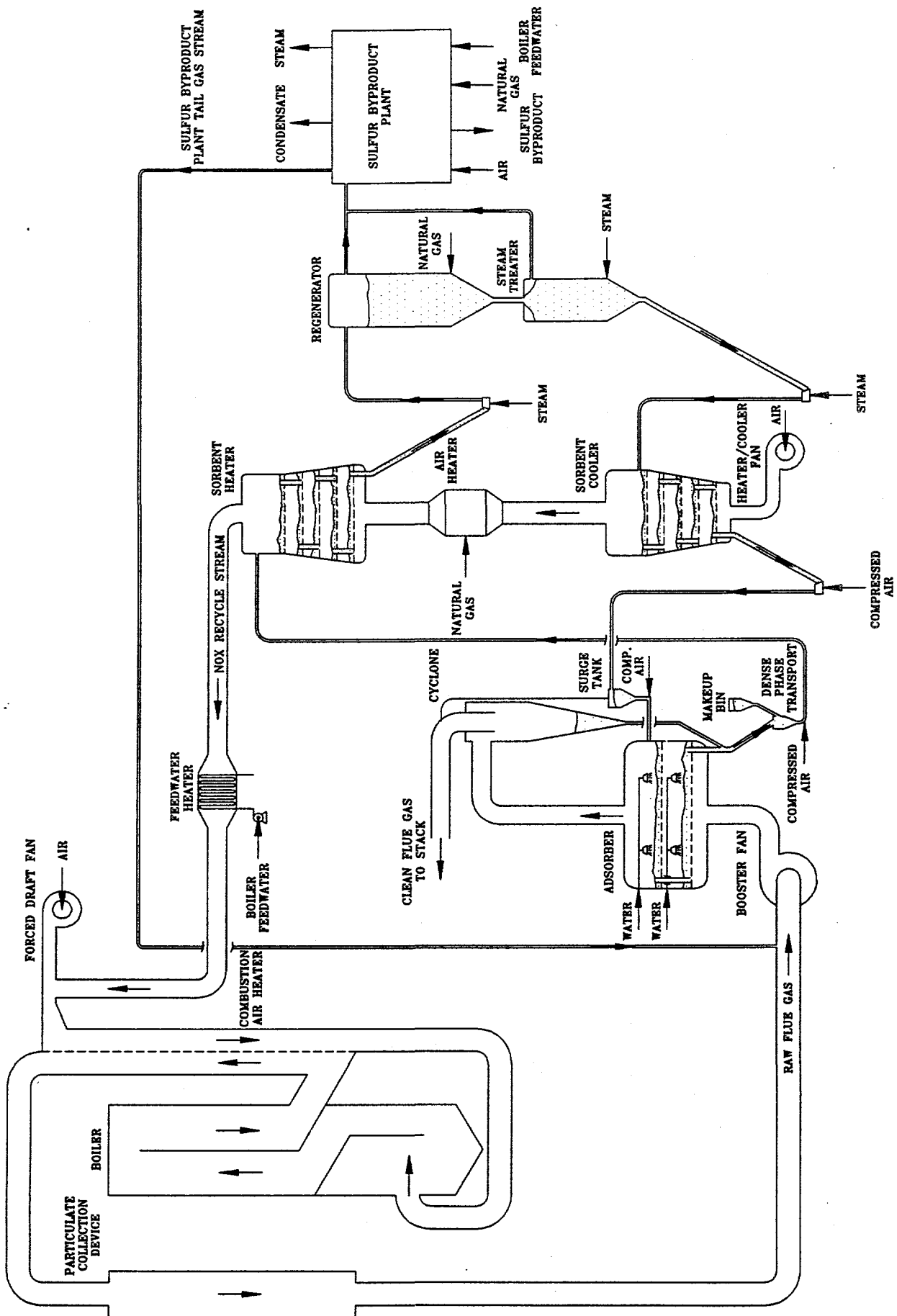


Figure 1. NOXSO Process Diagram

Regenerated sorbent exits the cooler at 300°F. It is directed to the adsorber completing the sorbent cycle.

Ambient air which is forced through the sorbent cooler by the heater-cooler fan exits the sorbent cooler at approximately 900°F. This preheated air then enters the air heater where it is heated to approximately 1350°F so it is capable of heating the sorbent exiting the sorbent heater to 1150°F.

2.0 PROJECT DESCRIPTION

The objective of the NOXSO Demonstration Project is to design, construct, and operate a flue gas treatment system utilizing the NOXSO process at Ohio Edison's Niles Plant Unit #1. The effectiveness of the process will be demonstrated by achieving significant reductions in emissions of sulfur and nitrogen oxides. In addition, sufficient operating data will be obtained to confirm the process economics and provide a basis to guarantee performance on a commercial scale. Ohio Edison's Niles Plant Unit #1 generates 115 MW of electricity and 275,000 scfm of flue gas while burning 3.5% sulfur coal.

3.0 PROJECT STATUS

The project is presently in the project definition and preliminary design phase. This phase was included in the project to allow completion of process studies and preliminary activities which could be conducted in parallel with NOXSO's pilot plant project being conducted at Ohio Edison's Toronto Power Plant.

NEPA Compliance

An updated EIV including responses to comments made by the DOE, SAIC, and Ohio Edison and an updated toxicity study of attrited sorbent was submitted to the DOE. SAIC is preparing an environmental assessment (EA) from the EIV.

Preliminary Engineering

Engineering work during the last quarter focused on reducing the tower height of the NOXSO process. The original design, a scale-up of the current Proof-of-Concept (POC) plant configuration, gave a tower height of 205 feet. This relatively tall plant height necessitated large amounts of structural steel to support the vessels and substantial foundations to support the structure and provide protection against large bending moments. The steel and foundations became a significant portion of the plant cost thus leading to engineering studies that would allow the tower height to be reduced.

The new general arrangement that was developed includes long horizontal vessels rather than cylindrical vessels, the sorbent heater and cooler placed side-by-side rather than stacked, and the use of dense phase transport systems in place of J-valves. The general arrangement drawing is shown in Figure 2. This particular arrangement offers three main advantages over the previous arrangement. First, the long horizontal vessels (12'x 50' nominal) makes the sorbent approach plug flow on each stage of the sorbent heater and sorbent cooler. The approach to plug flow improves the heat transfer efficiency per stage and allows the use of four stages instead of five (as with the cylindrical vessel design) while still achieving the same overall heat transfer efficiency. There are two stages in each sorbent heater/sorbent cooler vessel shown in Figure 1. The drawing depicts a total of six heater stages and four cooler stages. Future general arrangements will reflect four heater stages as well. Figure 3 shows a comparison of the gas flow rate required to heat the sorbent in the sorbent heater if the sorbent behaves as a continuous stirred tank reactor (CSTR) or as a plug flow reactor (PFR). The original cylindrical vessel design is the base case and F_g/F_{go} equals 1 for the five-stage design. If the sorbent would attain ideal plug flow in the horizontal vessels, a three-stage sorbent heater would be adequate. However, the actual flow pattern will be between plug flow and mixed flow so that four stages will be used. The second advantage of this general arrangement is that the tower height is reduced from 205 feet to 89 feet and the top platform is only 48 feet high. The subsequent reductions in structural steel and foundations is expected to have a positive impact on the overall plant cost. The third advantage is that the sorbent heater, sorbent cooler and adsorbers can now all be shop fabricated and shipped to site rather than be field erected. This should reduce the vessel cost and shorten the construction time.

One drawback to this new arrangement is that where J-valves were used to transport sorbent previously, dense phase systems will now be required; specifically from the sorbent heater to the regenerator and from the regenerator to the sorbent cooler. In each of these applications the sorbent temperature is in the range from 1050-1200°F. An equipment specification was written which included a drawing showing the vertical and horizontal runs required of each system. Bids are still pending.

A specification was also prepared and issued for the shop fabricated horizontal vessels. A separate specification was issued for the vessel internals, specifically the grid plates and downcomers.

A preliminary instrument list was prepared and issued in March. A new set of P&ID's was issued in April. As part of the NOXSO optimization program, the new P&ID's were reviewed and any non-essential instruments were eliminated. Non-essential instruments included any instrument that was not required to either control the process, maintain process safety, or to close material and energy balances.

Single line electrical drawings were updated and issued. These drawings included the 2400 V single line electrical, the 480 V substation single line electrical, and the 480 V motor control center single line electrical.

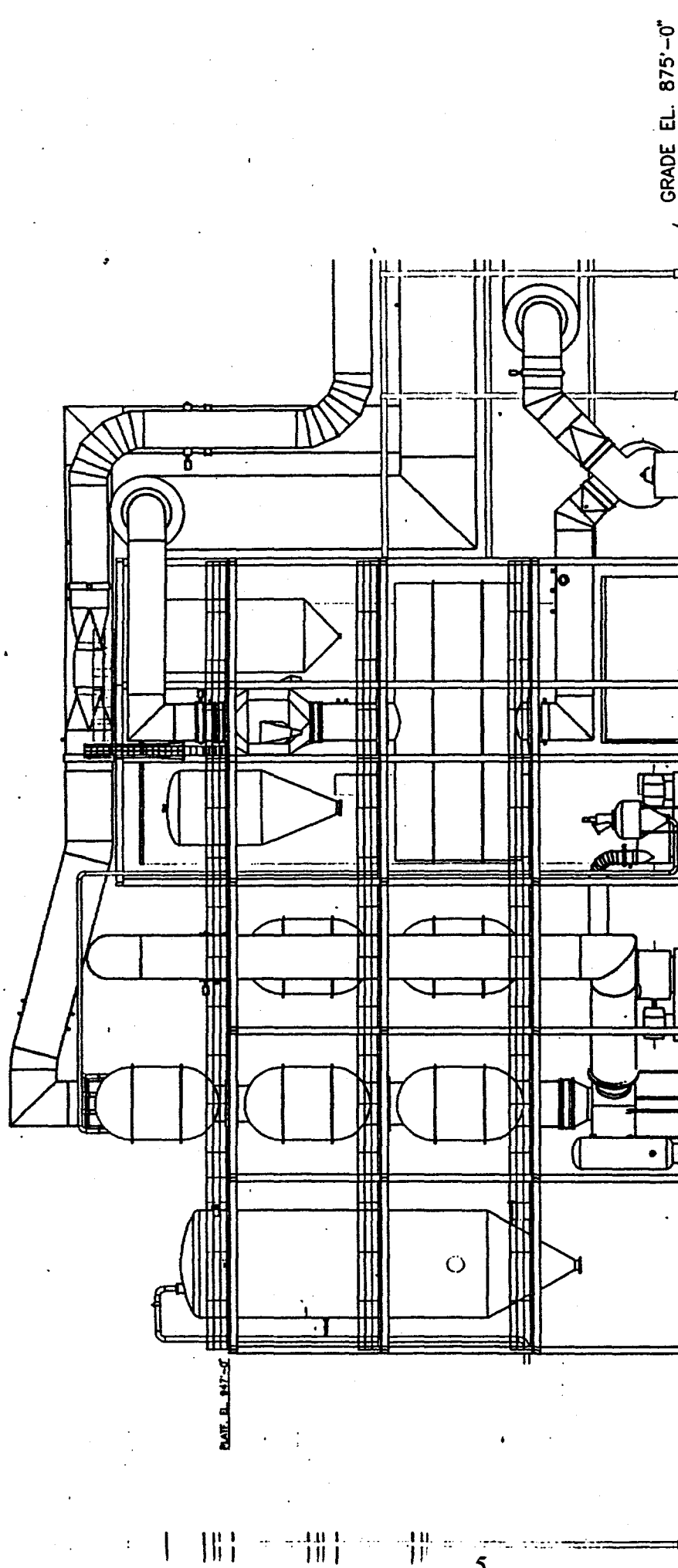
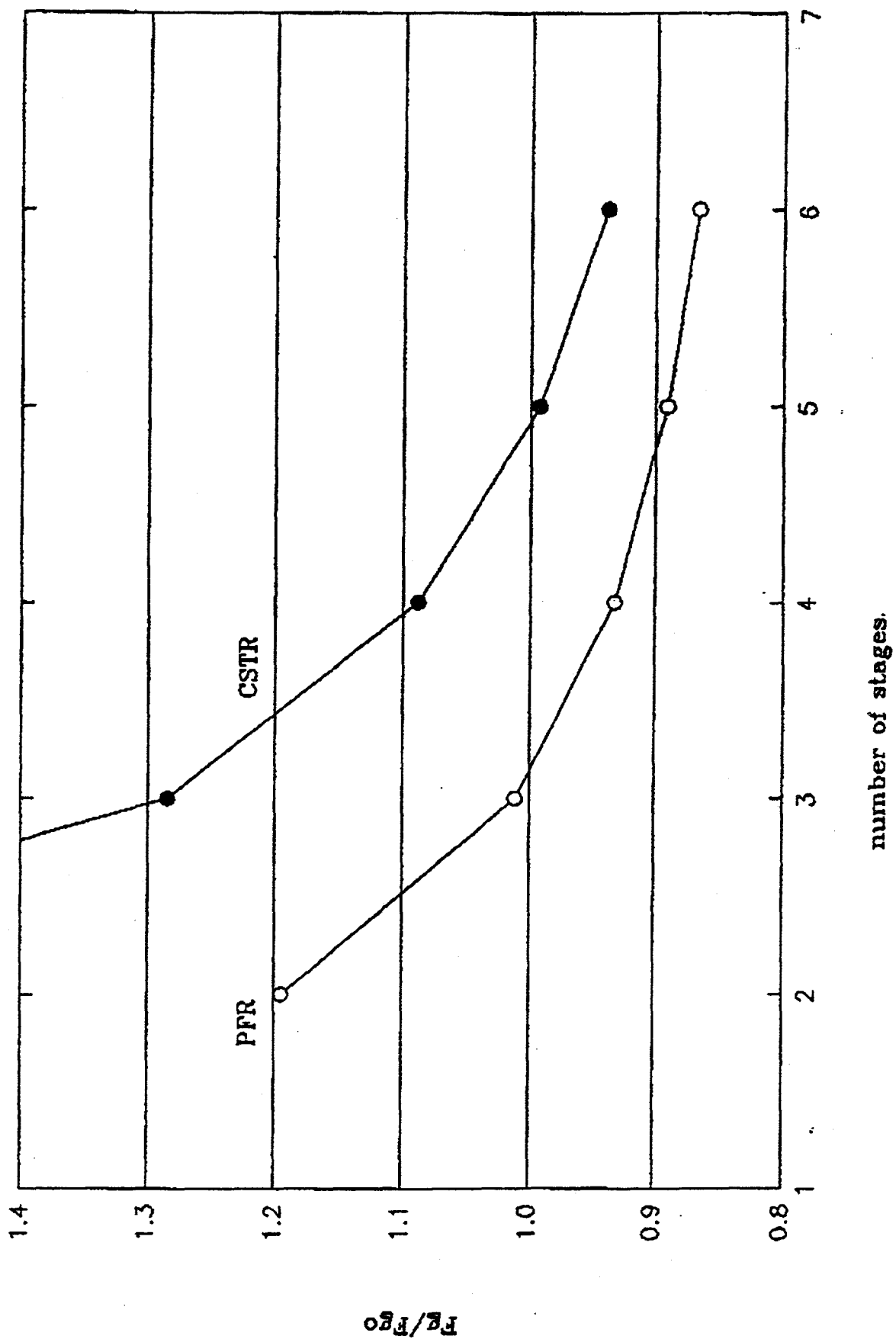


Figure 2. EQUIPMENT ARRANGEMENT #3

Figure 3. SORBENT HEATER



Nitrogen Oxide Studies

No nitrogen oxide studies were conducted during this reporting period.

Process Studies

NOXSO Pilot Plant

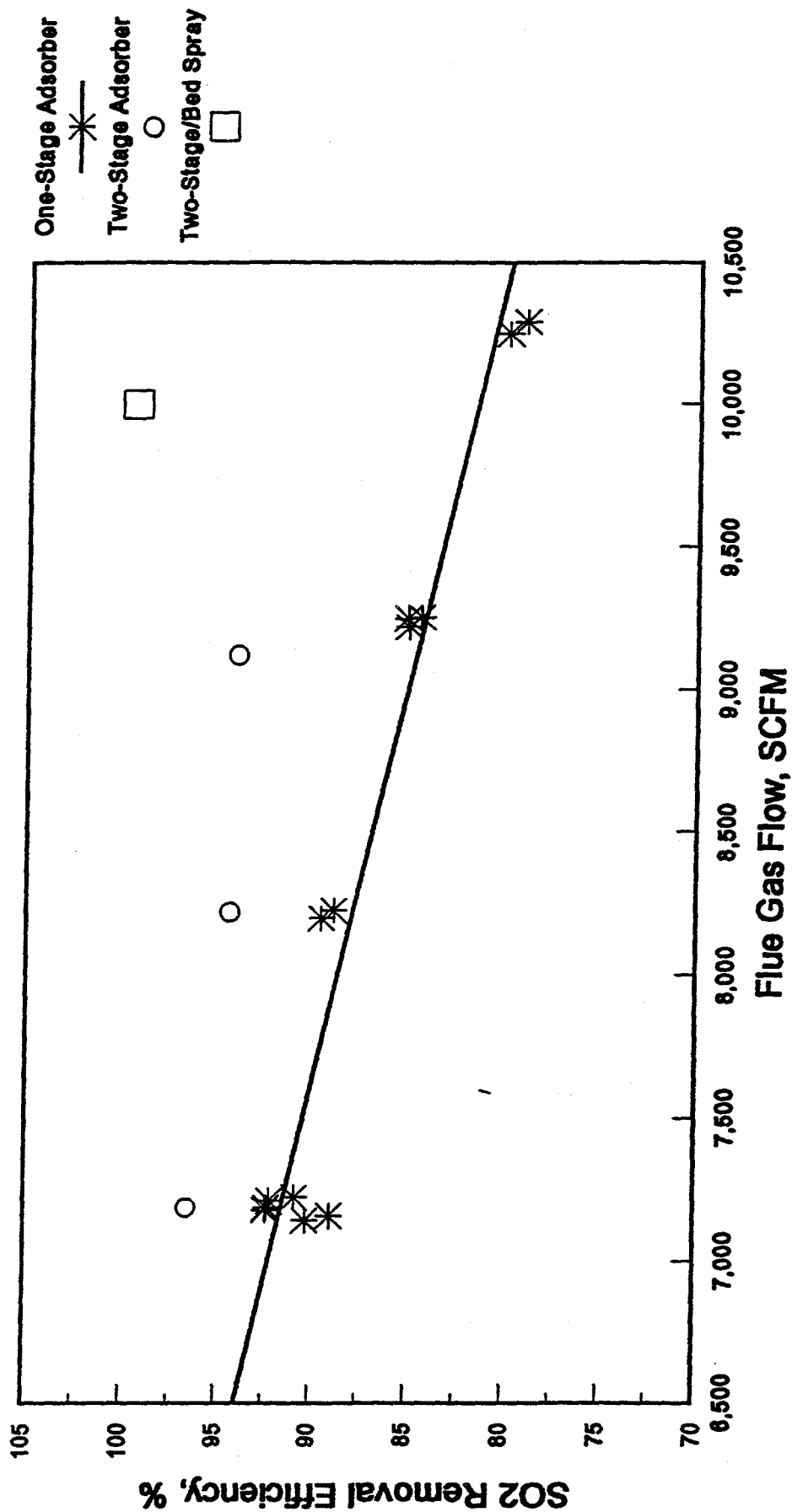
Tests performed at the POC were mainly to determine the effectiveness of the two-stage adsorber and in-bed water spray. Flue gas SO₂ and NO_x concentrations were increased to anticipated Niles conditions using bottled gases to assess the performance expected at Niles.

Figures 4 and 5 compare the one-stage and two-stage adsorber test results for SO₂ and NO_x respectively. In both cases the two-stage adsorber shows a significant improvement over the single stage results. In addition, the point represented by the square includes the in-bed water spray. An improvement greater than would be expected with just the two-stage adsorber is observed. These test results indicate that both the addition of a second adsorber stage and an in-bed water spray improves adsorption performance. Both of these features have or will be incorporated into the demonstration plant design.

Typical SO₂ and NO_x concentrations in the Toronto flue gas are 1400-1900 ppm SO₂ and 250-450 ppm NO_x. At Niles, after recycle, expected flue gas concentrations are 2650 ppm SO₂ and 970 ppm NO_x. To simulate the Niles flue gas, bottled SO₂ and NO were added to the flue gas to increase the concentrations to Niles values. These flue gas spike tests are summarized in Table 1. The test conditions for each spike test are listed and compared to the anticipated conditions at the Niles plant. Based on the test results, the current estimate for pollutant removal efficiency at Niles is as follows:

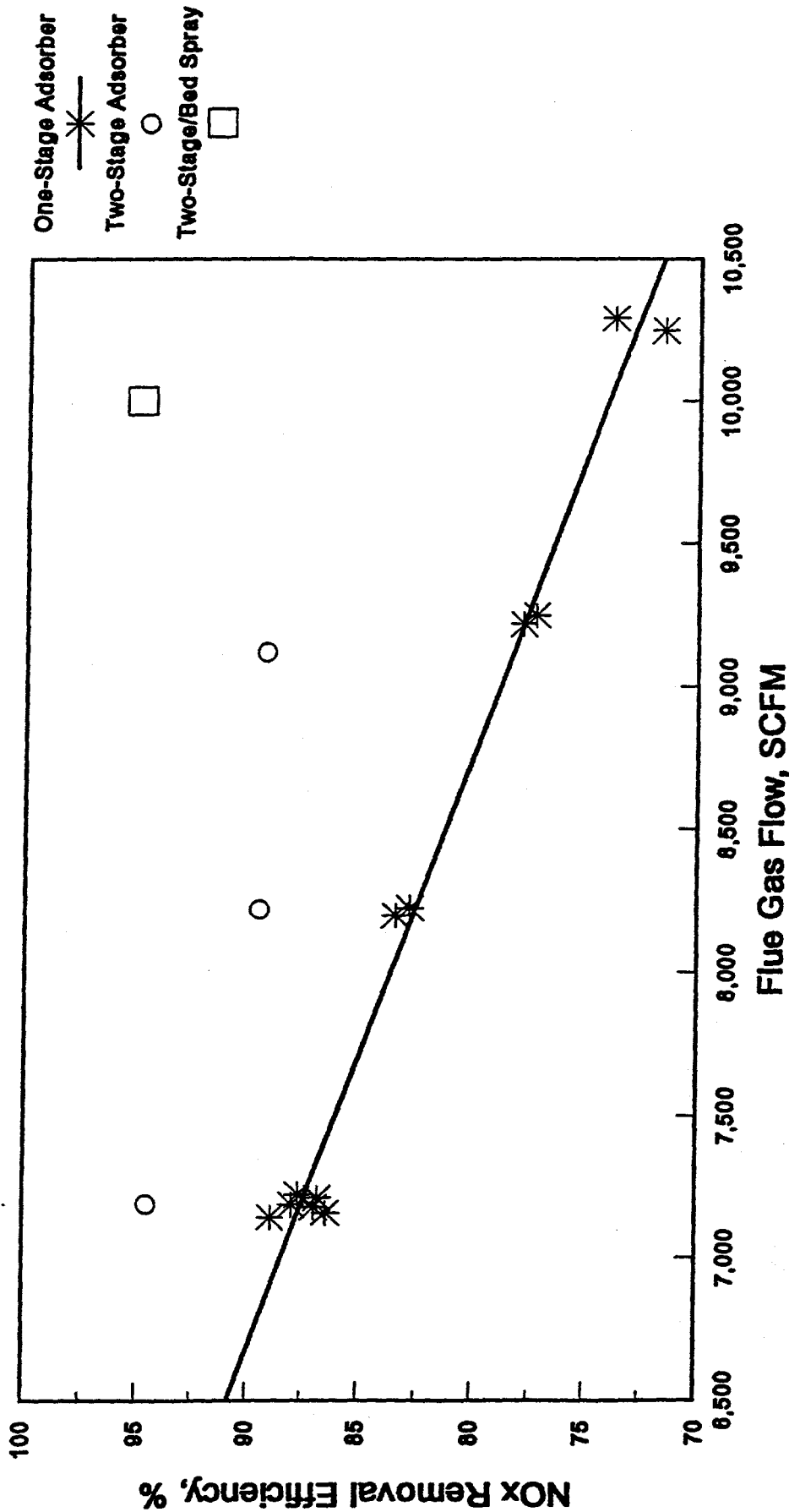
Adsorber SO ₂ efficiency	98.7%
Net SO ₂ efficiency	98.5%
Adsorber NO _x efficiency	87.9%
Net NO _x efficiency	80.1%

NOXSO PILOT TEST
Figure 4. ONE-STAGE vs TWO-STAGE ADSORBER



10,000 PPH
14 "H₂O, 7 & 7 "H₂O (two stage)
342-349 F, 333-344 F (two stage)

Figure 5. NOXSO PILOT TEST
ONE-STAGE vs TWO-STAGE ADSORBER



10,000 PPH
14"H₂O, 7 & 7 "H₂O (two stage)
342-349 F, 333-344 F (two stage)

Table 1. TEST CONDITIONS FOR SPIKE TEST/SIMULATION OF NILES CONCENTRATIONS				
	Test #1	Test #2	Test #3	Test #4
Test Duration (hr)	3.5	1.7	2.7	-
Adsorber Temperature				
-top	308	251	252	250
-bottom	288	256	254	250
Linear Velocity (ft/sec) @ Condition	2.4	2.3	2.0	2.8
Sorbent Residence Time (min)	52	45	46	52
Sorbent/Flue Gas Ratio (lb/lb)	0.24	0.24	0.20	0.24
NO Concentration (ppm)	917	1000	1167	971
SO ₂ Concentration (ppm)	2580	2365	2635	2650
Adsorber NO _x Removal (%)	87.5	85.2	86.0-90.7	87.9
Adsorber SO ₂ Removal (%)	97.4	99	99	98.7
NO ₂ Slip (ppm)	60	25	73	24
Bottom Bed Heater (°F)	1160	11160	1175	1150
Residual Sulfur (wt%)				
@Start	0.46	0.51	0.47	-
@End	0.71	0.74	0.87	-
Regenerator Residence Time (min)	42	42	45	45
Steam Treater Residence Time (min)	12	12	12	15

Demonstration Plant

Tests were conducted at the Clairton Research Center on an L-valve to generate data for developing design equations. The variables studied in the test program were aeration gas flow rate, conveying gas flow rate, and feed tank pressure. The pressure was measured at various points along the riser and downcomer. Future work will include correlating the data with equations for prediction of solids circulation rate given the L-valve dimensions and operating conditions.

A technical and economic study of sulfur by-product options has been initiated. The original plan was to make elemental sulfur, however the potential increase in by-product revenue (see Table 2) for producing sulfuric acid or liquid SO₂ make these options attractive.

Table 2. Sulfur By-products Revenue			
Sulfur By-product	Production Rate*	Net Value	Net Revenue
Liquid Sulfur	8,190 TPY	\$50/ton	\$409,500
Sulfuric Acid	25,000 TPY	\$50/ton	\$1,255,000
Liquid SO ₂	16,380 TPY	\$150/ton	\$2,457,000

* Based on 70% capacity factor and 95% SO₂ removal efficiency.

Information regarding the feed stream has been provided to Chemetics, Inc. They will provide a technical proposal and estimate to produce both sulfuric acid and liquid SO₂.

Plant Demonstration

No activities were conducted regarding plant characterization this reporting period.

Site Survey/Geotechnical Investigation

Additional borings were made to better define the subsurface conditions at the site. Due to the height and weight of the NOXSO tower, the relatively poor soil conditions, and the sparsity of soil borings, the necessary foundation system was complicated and costly. The objective of the additional borings is to better define the subsurface in an attempt to design a more cost effective foundation system. Professional Service Industries, Inc. has completed the field work. A final report with foundation recommendations is forthcoming.

Permitting

No permitting activities were conducted during this reporting period.

4.0 SUMMARY

The EIV has been submitted to the DOE for use in preparing the environmental assessment (EA). A "low profile" general arrangement option which includes process vessels which are shop fabricated and field assembled is being evaluated. In addition to reducing the size and complexity of the structural steel and foundation, the shop fabricated vessels will reduce the field construction time. Testing at the NOXSO pilot plant continued to focus on increasing NO_x removal efficiency at Niles flue gas conditions. Using a two-stage adsorber and in-bed

water spray cooling in the adsorber, the removal efficiencies for Niles are estimated to be 98.5% for SO_2 and 80.1% for NO_x . A study of the various sulfur by-product options (liquid sulfur, sulfuric acid, and liquid SO_2) is being conducted. The technical characteristics of producing each by-product and how these characteristics can be interfaced with the NOXSO process is of primary concern.